BOL|RAL|M|0012-1M
SPIRE/RAL-MOM-0000104

FIRST BOL CRATING STUDY MEETING

10/2/97.

ATTENDEES

BRUCE SWINYARD	- RAL.
PETER HASTINGS	- ROE
Martin Caldwell	- RAL.
Eli Atad	- ROE
François PAJOT	IAS
ROGER EMERY	- RAL.
Jean-Paul BALUTEAU	- LAS
KJETIL Kjetil [DOHLEN@OBMARA.CNRS-MRS.FR]	- OBS DE MARSEILLE / LAS
SYE MURRAY	- QMW
Emmanuel CAUX	- CESR
MATT GRIFFIN	- QMW

Additional notes to the View graphs for the FIRST-BOL Grating Study Group Meeting 10/11 Feb 1997

B. Swinyard - RAL
14 February, 1997

Present:	B.Swinyard	- RAL
	P. Hastings	- ROE
	M. Caldwell	- RAL
	E. Atad	- ROE
	F. Pajot	- IAS
	R. Emery	- RAL
	J-P. Baluteau	- LAS
	K. Dohlen	- ObsM/LAS
	A. Murray	- QMW (part)
	E. Caux	- CESR
	M. Griffin	- QMW
	P. Ade	- QMW (part)

Summary:

The status of the FIRST mission was outlined by Matt; it is clear that the situation is evolving rapidly but must become settled by the middle of the year if the launch in 2005/6 is to be credible. The satellite will be a cryostat only with a 4.5yr lifetime if it is launched to L2.

The science requirements as set down by the SAG were reviewed (see view graphs). The original spec. for R=3000 between 200-400 um has been changed to R=1000 between 200-300 optimised at 250 um. Spectroscopic imaging is still a requirement. Both photometery and spectroscopy should be background limited by the telescope emission.

Jean-Paul presented a case for optimising the mission for high red shift surveys. In order to do this he believes that imgaing spectroscopy is unnecessary and that the resolution required is of the order of 300-400. Also in order to see all the FIR lines redshifted into the BOL wavelength range it is necessary to have wavelength coverage up to certainly 350 um and desirable to have it up to 450 um.

The concensus of the meeting was to keep as close as possible to the SAG recommendations for the time being, with a slight re-emphasis towards higher wavelengths (350 um) especially for sensitivity. A list of basic assumptions for the instrument design were drawn up (see view graphs and below).

Actions:

I) Obtain PC Grate grating efficiency code - BMS/PARA

II) Draft an outline focal plane design - MJG/PARA

III) Summarise scientific arguments against optimising for imaging spectroscopy and resolution of 1000 - JPB

IV) Draft a note on the advantages of a grating instrument over a Fabry-Perot - MJG+others as required

Summary of discussions on Optical Design:

The three groups interested in the optical design of the instrument met in a splinter group to define the parameters for the optical design of the BOL instrument under the following basic assumptions agreed in the "plenary" session:

1. Spectroscopy Resolving Power: 1000@250um nominal

2. Wavelength Coverage: Spectroscopy - 200-350um - reaching 350 is important for the high-z survey.
   Photometry 200-600um.

3. Grating Temperature: <5K

4. Photometry/Spectroscopy: Beams for two sub-instruments divided before the 4K enclosure.
   Do not require the same FOV or to image the same portion of the sky simultaneously.
   FOV 225" as per PDD.
   Baseline is that there will be a filter wheel for the photometer channel.

5. Imaging Spectroscopy: Yes as baseline.

6. System Throughput: >10% for spectroscopy; >30% for Photometry.

7. Straylight control (see also optical requirements below): Pupil as close as possible to the grating.
   Minimise beam folding.
   Lyot stop in photometer may be desirable.

8. Focal Plane: Photometer focal plane will have two channels for long and short wavelengths (200-400um and 400-600um (TBC))
   Detector arays and 2K optics should be as compact as possible.
   Minimum size of pixel is 2.5-2.6mm with pitch of 4mm.
   Pixels can be larger than the minimum size.
   25 pixels can be dedicated to spectroscopy.
   61 pixels can be for the short wavelength photometer array.
   37 pixels can be for the long wavelength photometer array.

9. Chopping: There will be sky chopping for both the spectrometer and photometer.

10. Final focal ratio: No faster than F3.

Optical Requirements
The splinter meeting agreed the following optical requirements for the design of the photometer and spectrometer channels. The optical requirements are set out here in order starting at the focal plane for each sub-instrument - this does not constrain the designers to using entirely separate optics for the two sub-instruments if sharing parts of the optical train proves effective.

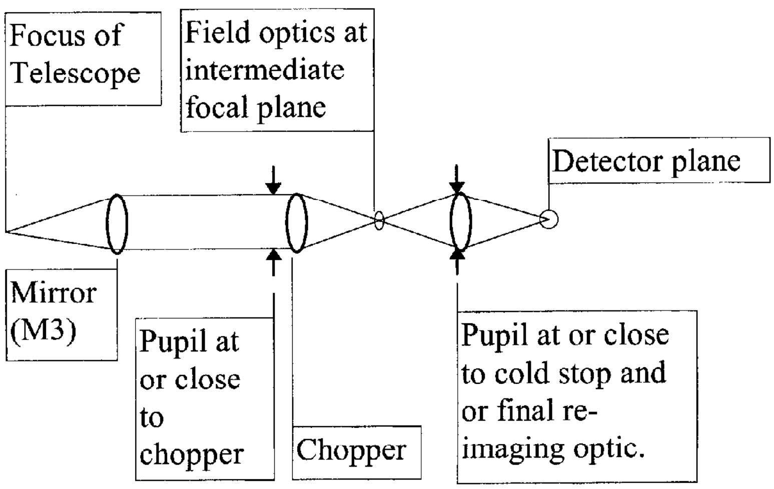
Photometer:
Focal Plane at detector arrays.
Pupil Plane at cold stop.
Filters on wheel placed close to pupil plane.
Pupil plane at chopper.

Spectrometer:
Focal plane at detector array.
Pupil plane at cold stop between grating and detectors is desirable.
Pupil plane at or close to grating.
Focal plane at slit
Pupil plane at chopper

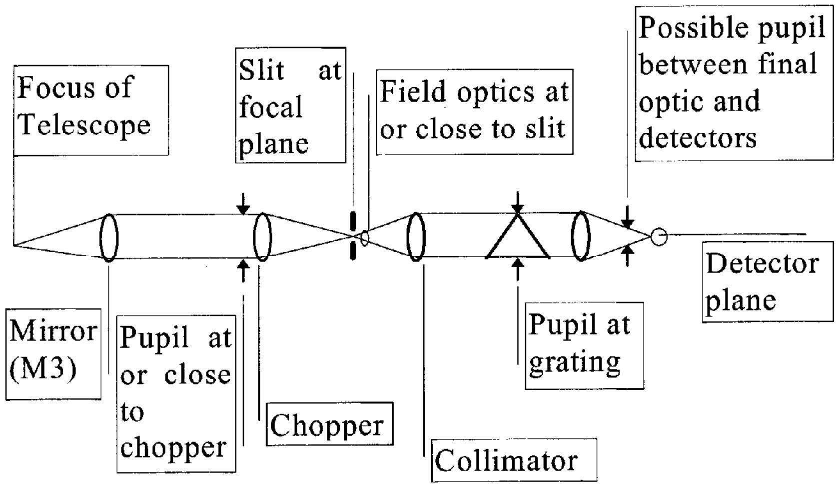
The sub instruments will view diferent portions of the BOL portion of the telescope FOV. The baseline for achieving this is by viewing through two separate "holes" with separate choppers.

Sketch of optical trains:
The splinter group decided upon the following outline optical trains for the two channels:

Photometer:



Spectrometer:



Actions/next meeting:
The three design groups (ROE, RAL and LAS) will circulate outline designs within two weeks and comment on these by e-mail. The next meeting proper will be in the week before the Grenoble meeting (7-11th April), probably in Edingburgh

Current Status of FIRST

- Possible launch in 2005/6

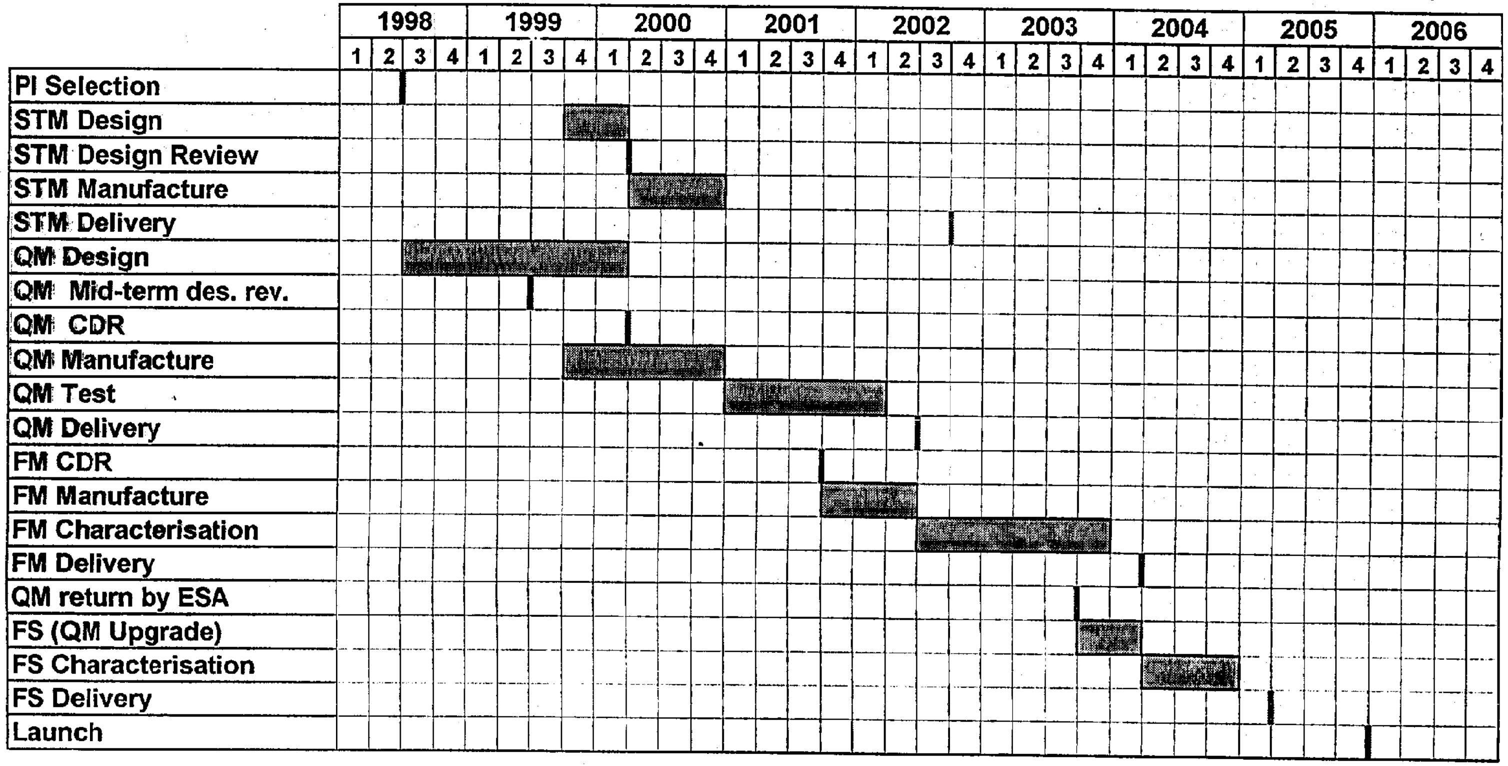
- Possible merger with PLANCK
  (to be studied)

  Implications for the BOL ??

  ESA decision by June SPC meeting ?

- Grenoble symposium will be focus of debate and assessment of the scientific and technical issues.

FIRST POSSIBLE BOL INSTRUMENT DEVELOPMENT SCHEDULE



Version 2
9 Jan. 1997

Aims of this Workshop

- Consider relative merits of grating and F-P options
  - scientific
  - technical
  - cost
  - risk

- Establish baseline assumptions for grating design (including photometry capability)

Important parameters:

Size of focal plane arrays
Spectral and spatial sampling
Observing modes
Overall efficiency
Stray light control
Size and mass at 4 K and (15 - 20) K
Filtering requirements

BOL Science Requirements

Spectroscopy

- λ = 200 - 300 + μm
- $\lambda/\Delta\lambda$ ~ 1000 or better
- Background-limited by telescope emission
- Imaging

Photometry

- λ = 200 - 600 μm
- $\lambda/\Delta\lambda$ ~ 3 - 5
- Background-limited by telescope emission
- Imaging

Deep survey of high-Z galaxies is a high priority for FIRST

Advantages of Grating

- Simpler instrument construction, operation
- Reliability (F-P has mechanisms in series)
- Less development effort
- Lower cost
- Higher efficiency ?
- Better instrument response function
- More suited to spectral survey work
- Can more easily separate photometry and spectroscopy and optimise both

Disadvantages of Grating

- Not optimised for 2-D imaging spectroscopy
- Cannot easily get $\lambda/\Delta > 1000$

Observing Modes

- **Specific line of known λ**
  - **Single pixel**
  - **Mapping**
- **Full spectrum**
  - **Single pixel**
  - **Mapping**

- Assume n x n detector array
- Specific line of known λ

Mapping:	F-P is n times faster for same throughput
Single pixel:	F-P and grating equally fast

- Full spectrum

Mapping:	F-P and grating equally fast
Single pixel:	Grating is n times faster

- F-P better for mapping galaxies and S-F regions
- Grating better for full FIR spectra and deep surveys of objects of unknown redshift and

150-500 um DEEP BROAD-BAND SURVEYS
"considered most important overall key program with FIRST"

ONLY TWO (R=3) FILTERS CONSIDERED

F1: 200-280 um $z=5 \rightarrow \lambda = 40\ \mu m$

F2: 370-500 um $\lambda = 72\ \mu m$

SOURCES WITH BB LIKE SPECTRA
COLOR TEMPERATURE IN RANGE 3 TO 30 K

NO FILTER WHEEL NEEDED

ONLY ONE DICHROIC REQUIRED
PROVIDE SIMULTANEOUS 2 FIR MAPS

FOLLOW-UP SPECTROSCOPY

"a second, important step in the high redshift program"

EX.: LWS data on starburst galaxy (NGC 4038/39)

main cooling lines	line intensities (LWS)	line to continuum ratios				z	
		(LWS)	R(LWS)	R=1000	R=300	200um	350um
[CII]158um	3.7	1.6	263	6.1	1.8	0.3	1.2
[OIII]88um	4.7	0.42	147	2.9	0.86	1.3	3.0
[OI]63um	5.2	0.17	210	0.81	0.24	2.1	4.6
[NIII]57um	1.6	0.22	190	1.2	0.35	2.5	5.2
[OIII]52um	4.9	0.60	173	3.5	1.1	2.8	5.7

[OI] 146μm/63μm ~ 0.02 to 0.10

a. redshift obtained from ground-based follow-up :
   detection of lines at specific wavelengths
   high resolution and medium resolution equivalent in S/N ratio

b. redshifts determination require FIRST spectra :
   low resolution better to cover the maximum wavelength range in the shortest time
   i.e. 10 detectors array (pixel = spectral resolution)
   at R=300 only 30 spectral steps
   to cover the whole spectral range

GALACTIC SPECTROSCOPY

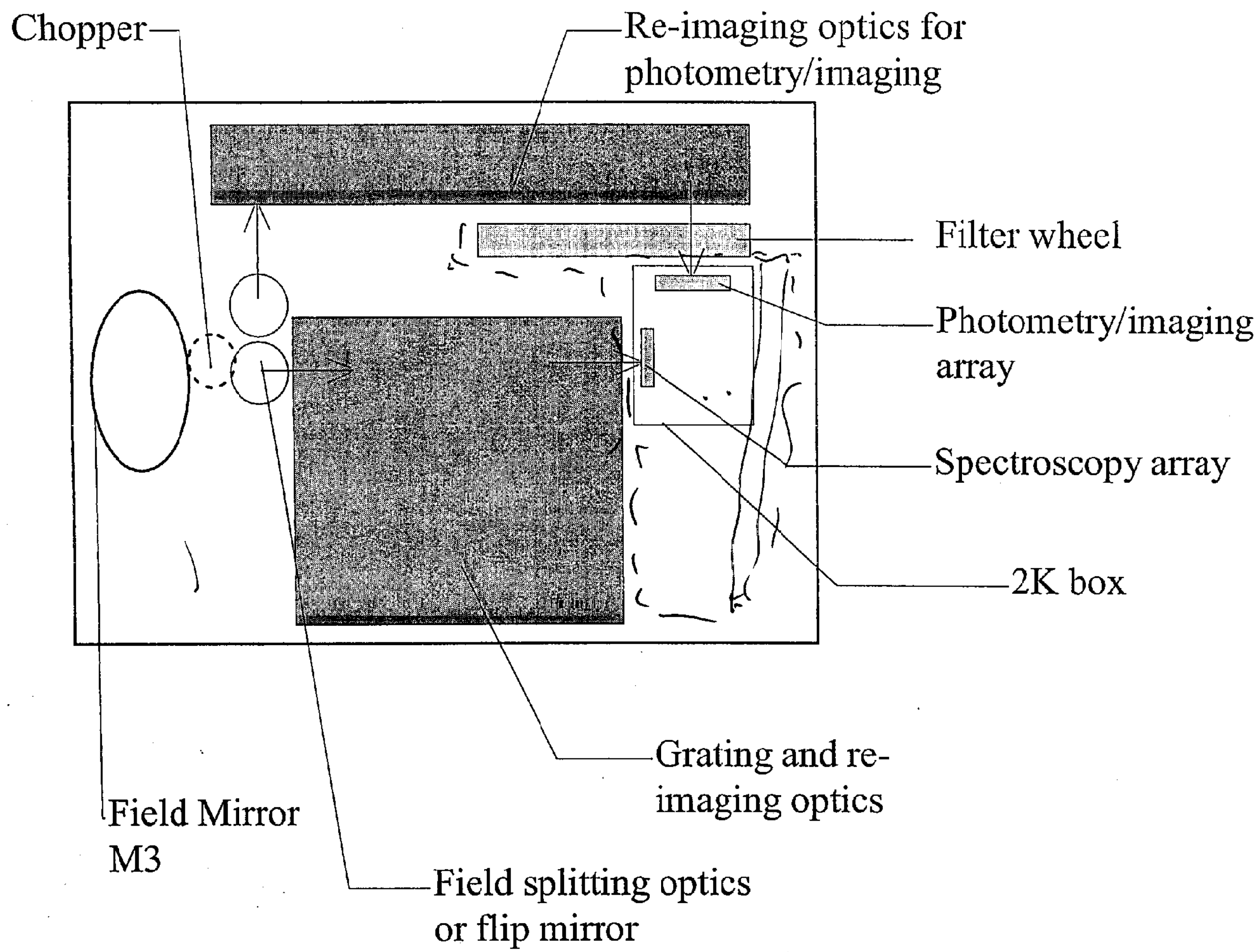
HIGH RESOLUTION BETTER

LWS: H_2O 179um line seen in absorption at R=298
4% toward compact HII regions
15% toward Sgr B2

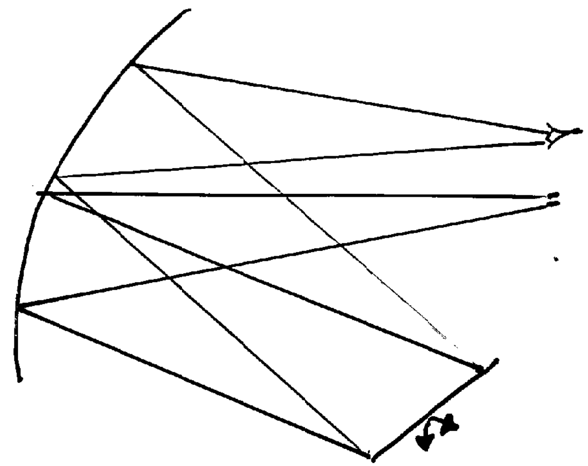
Lines of interest:

[CI]	370.4 um	1% of [CII] (COBE)	missed ?
[NII]	205.3 um	10% of [CII] (COBE)	

CO	J levels between 8 and 13	warm clouds
H_2O	only high rot. transitions	or shocks


Chopper
Re-imaging optics for photometry/imaging
Filter wheel
Photometry/imaging array
Spectroscopy array
2K box
Grating and re-imaging optics
Field Mirror M3
Field splitting optics or flip mirror

i) LITTROW

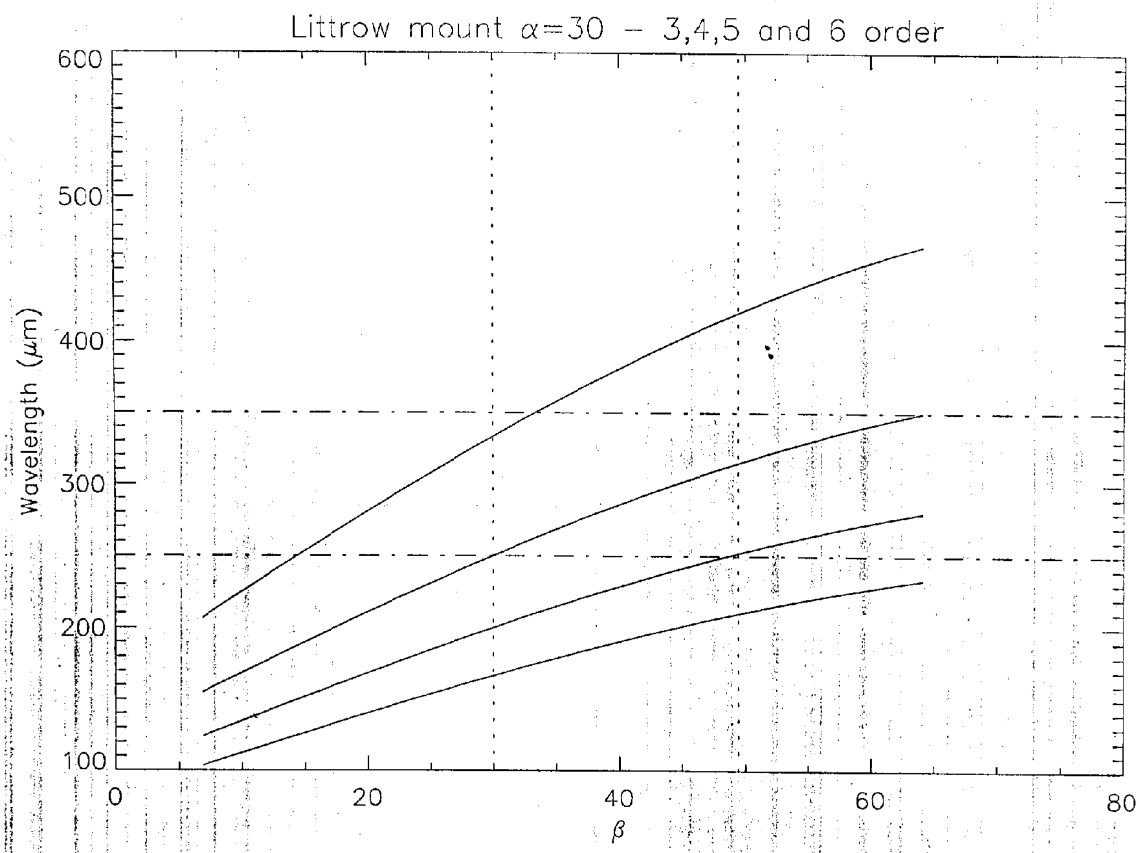


FOR

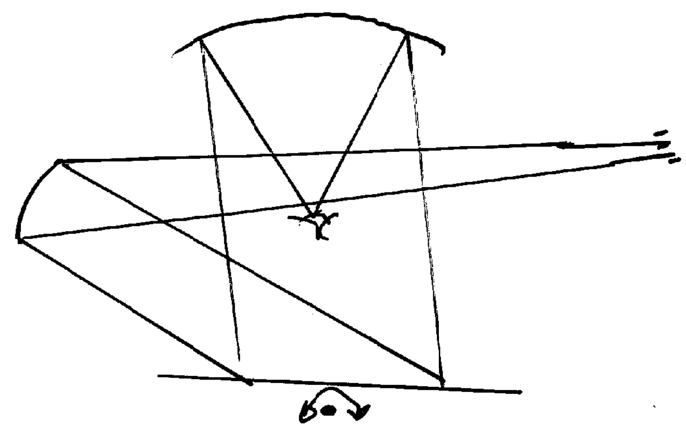
- The "classic" mount for plane grating
- Same optics in + out
- Best resolution
- Best efficiency?

AGAINST

- Same speed for input + output
- Big mirror necessary
- High angular dispersion → large focal plane array.
- Stray light control may be complex.


Littrow mount α=30 – 3,4,5 and 6 order
Wavelength (μm)
600
500
400
300
200
100
0
20
40
60
80
β

ii) "LWS"

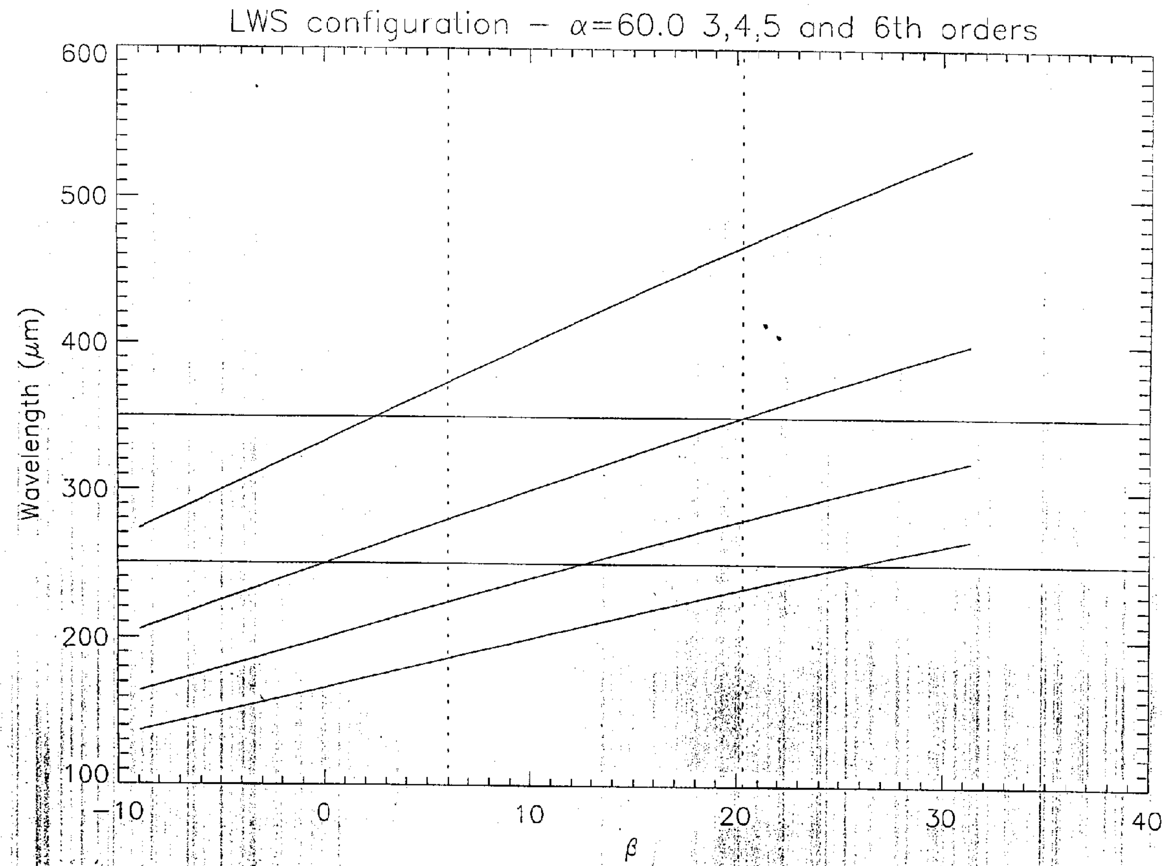


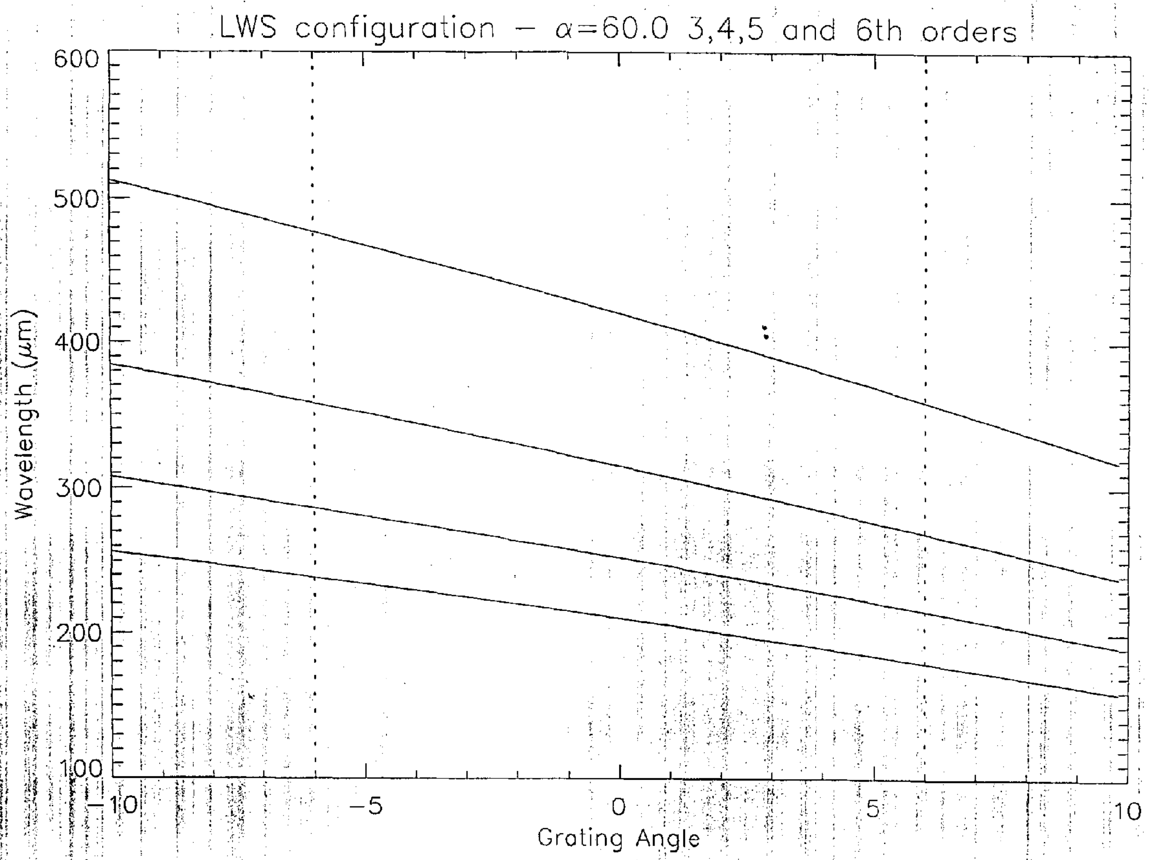
FOR

- Can minimize angular dispersion
- Different speed input and output beams
- Smaller mirror

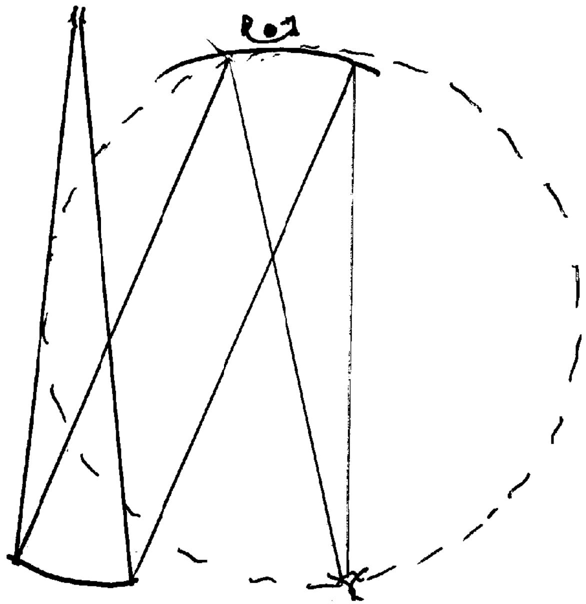
AGAINST

- Efficiency?
- Imaging quality may suffer 'cos off axis system


LWS configuration – α=60.0 3,4,5 and 6th orders
Wavelength (μm)
600
500
400
300
200
100
−10
0
10
20
30
40
β


LWS configuration – α=60.0 3,4,5 and 6th orders
Wavelength (μm)
600
500
400
300
200
100
Grating Angle
−10
−5
0
5
10

iii) WADSWORTH.



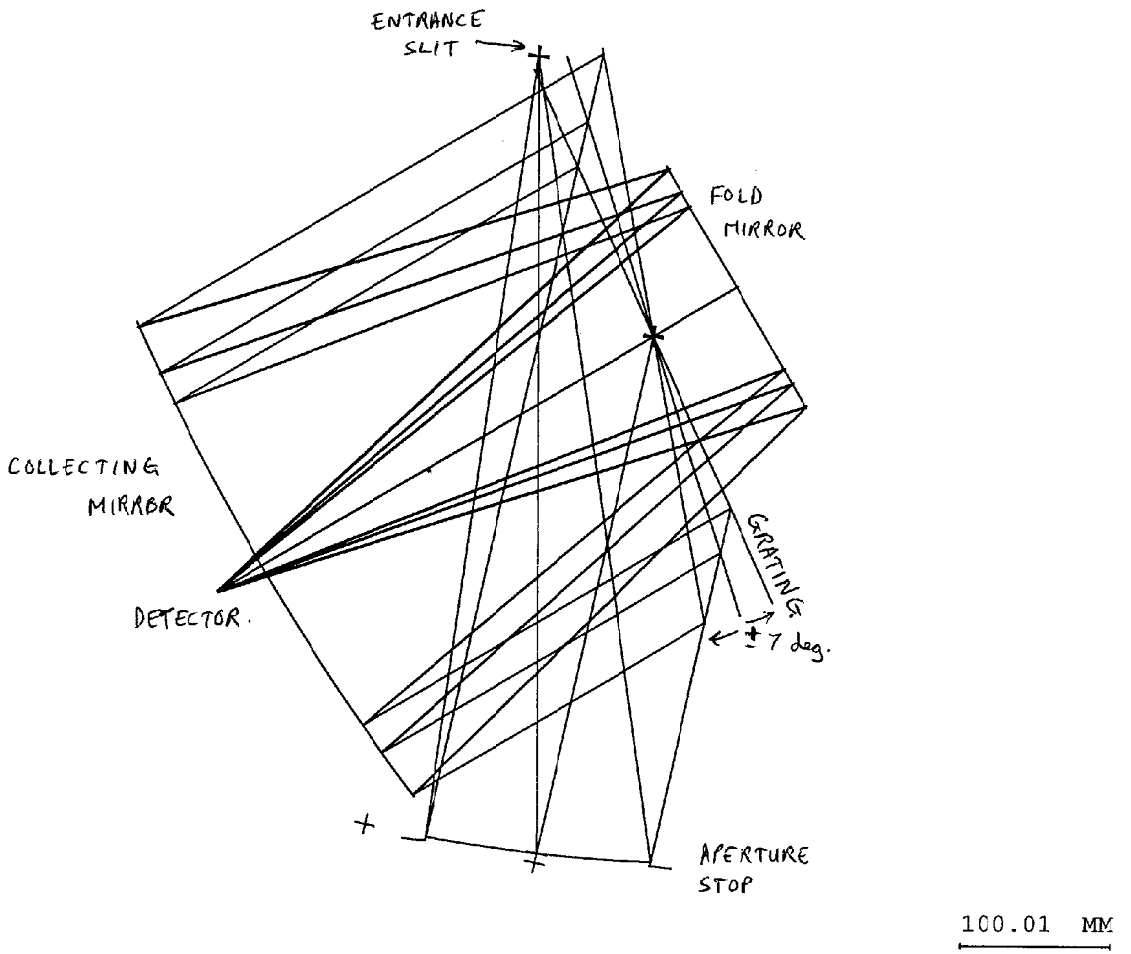
FOR

- Classic UV/Optical mount
- Gets rid of "Big" mirror
- Possibly more compact.

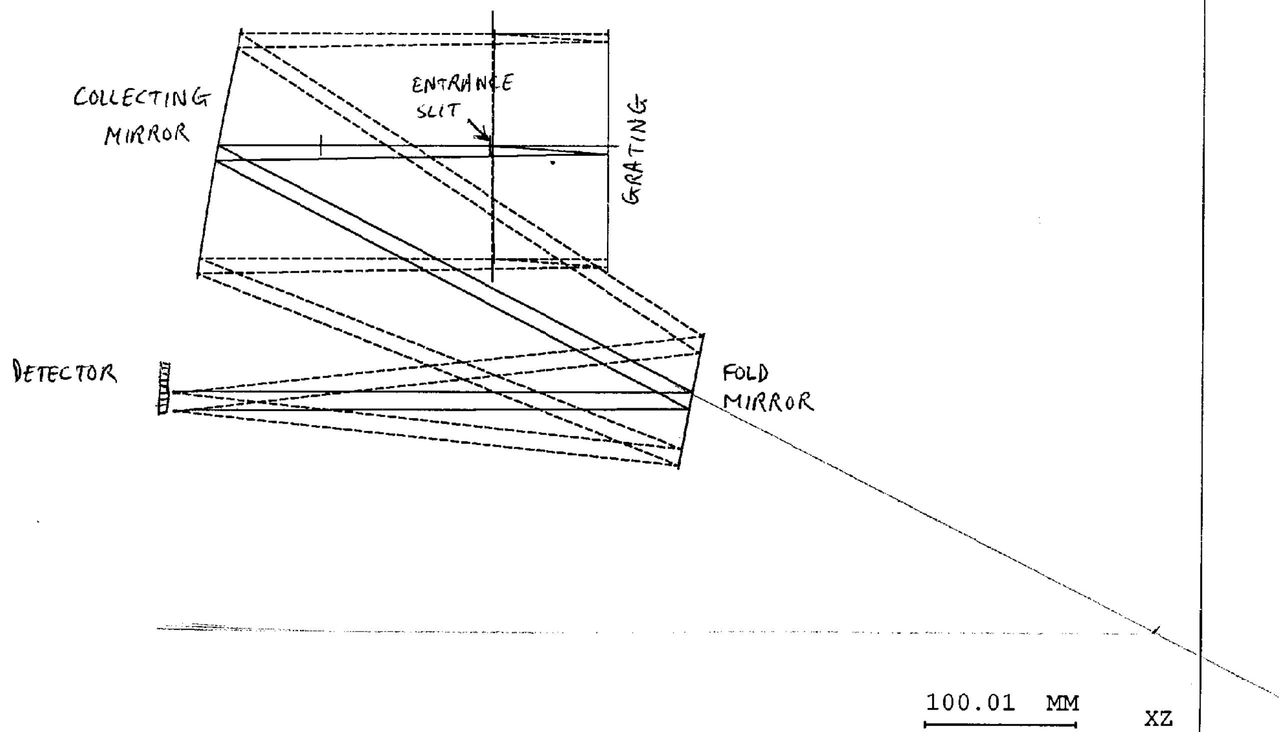
AGAINST

- Does it work at high λ?
- How does imaging quality suffer as grating angle is changed.?
- Does it work at low f number?

14:06:04 MEC



fir~~1~~ 3 mec 31-JAN-97



fir3

mec 31-JAN-97

FIRST BOL

Optical design of the F-P instrument

Optical concepts for dual-channel instrument

K. Dohlen
Observatoire de Marseille

Optical design of the F-P instrument

Optical concept due to J-M Lamarre:

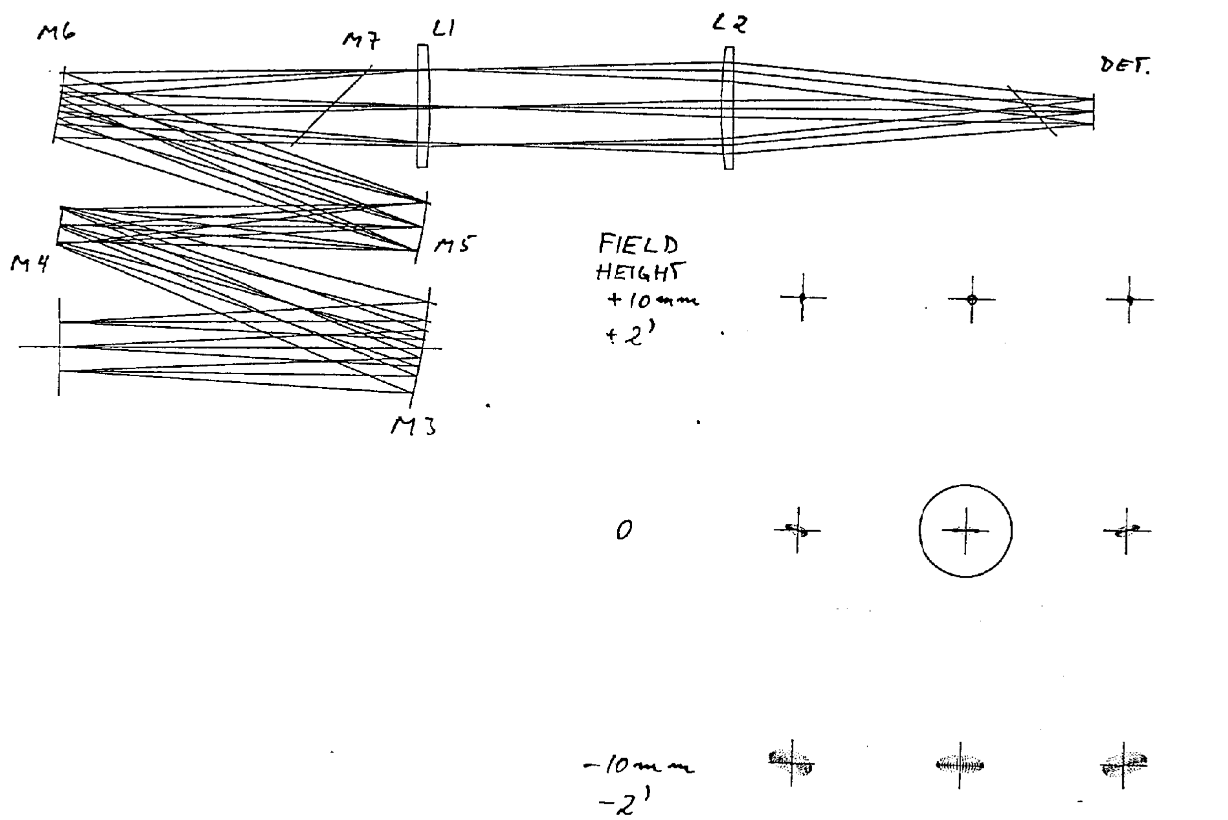
Input beam F/10
M3: Forms image of pupil Ø30mm at M4
M4: "Wobbling" for sky chopping, forms image at M5
M5: Forms pupil Ø60mm at L1
M6 and M7: Flat
L1: collimates beam Ø60mm for F-Ps and filters
L2: Focuses F/5 beam onto detectors
M8 and cold box: Flat mirrors and dichroic

Lens material:

Crystal Quartz cut to avoid birefringence
$n_o = 2.109 \pm 0.002$ ($n_e = 2.157 \pm 0.003$, $n_{avg} = 2.13 \pm 0.02$)

Throughput:

Mirror reflectivity very high (~98-99%)
Lens (t = 10 mm) absorbs 10 %, reflects 13% per uncoated surface
Hence transmittance: 68% per lens, 46% in total



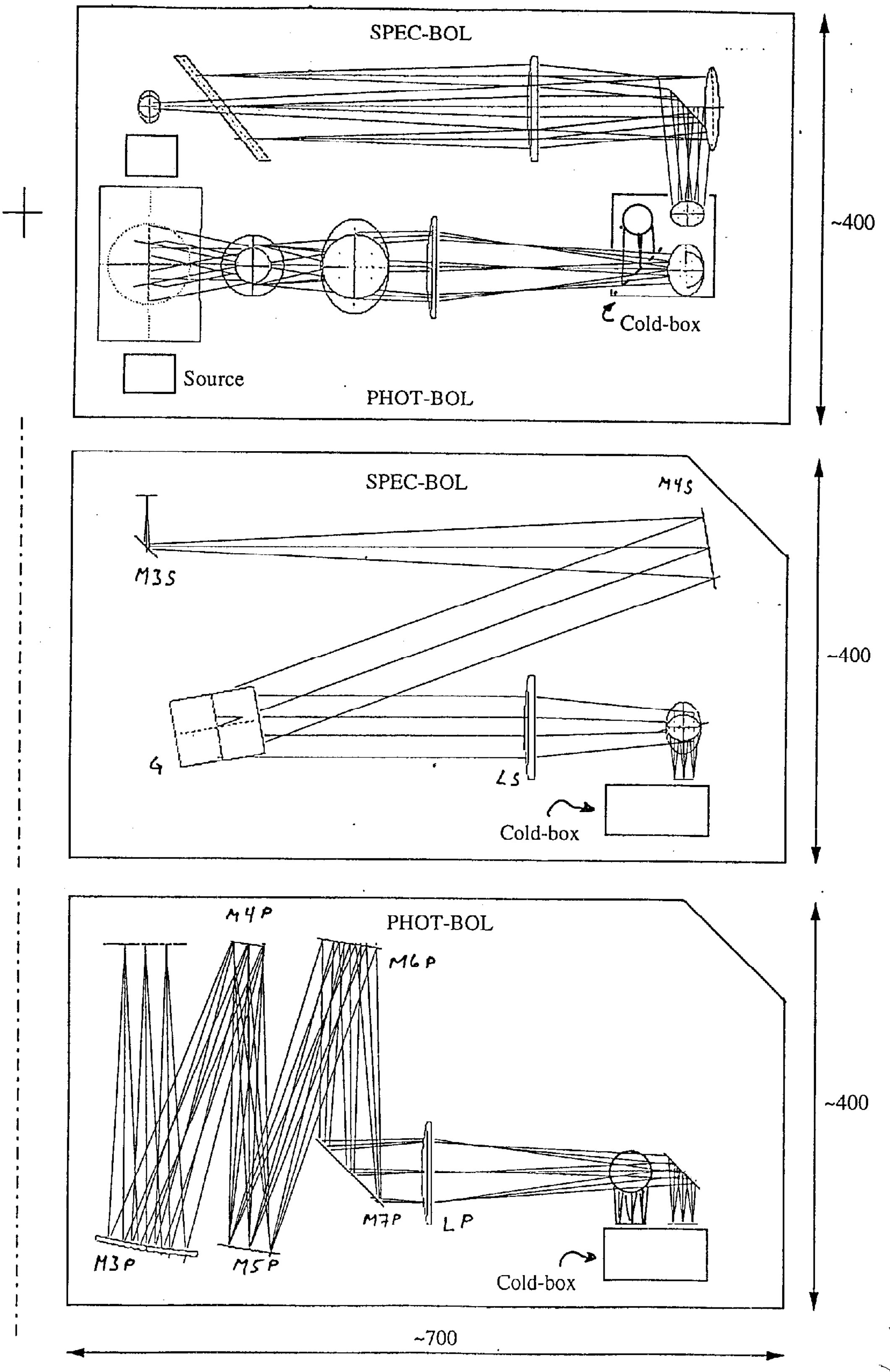
LENS Y-Z PROFILE
SCALE FACTOR 0.200 X
ID FIRST BOL DES. LAMARRE (FIRBOL05) 57

K.D. 02-06-1997 14-54-07

DUAL CHANNEL CONCEPT

Photometer, "PHOT-BOL"		**Spectrometer, "SPEC-BOL"**	
Wavelength range:	200 – 600 µm	Wavelength range:	200 – 350 µm
Focal ratio:	F/5	Focal ratio:	F/5
FOV:	~4 arcmin	IFOV:	25 arcsec
SW detectors:	200 – 350 µm	Detectors:	Row of ~10
	Ø 2 mm (25 arcsec)		Ø 2 mm
LW detectors:	350 – 600 µm	Resolving power:	>300
	Ø > 2 mm	Wavelength chopping	
No filter wheel, channel selection by dichroic and filters at detectors			
Sky chopping			

K. Dohlen, Observatoire de Marseille

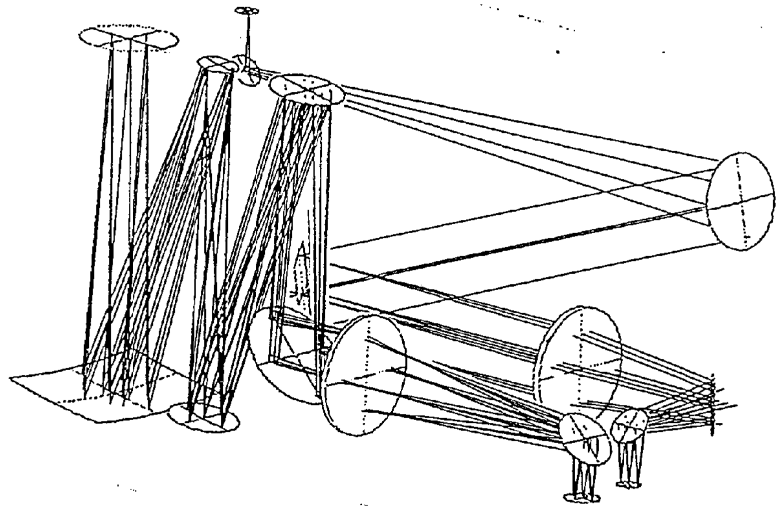


5/17

K.D. /OM/7.2.97

DUAL CHANNEL CONCEPT

Isometric view of the two channels together



PHOT-BOL

Optical concept:

Sky chopping required so require pupil early in the system

Need long (~300mm) BFL to enter Cold-Box (?)

Then need large (Ø60mm) beam at lens (or mirror)

Pupil at lens for acceptable performance

Hence copy Lamarre's system but with only one lens

Throughput

Crystal Quartz lens 10 mm thick: T = 68%

All-reflecting solution maybe possible

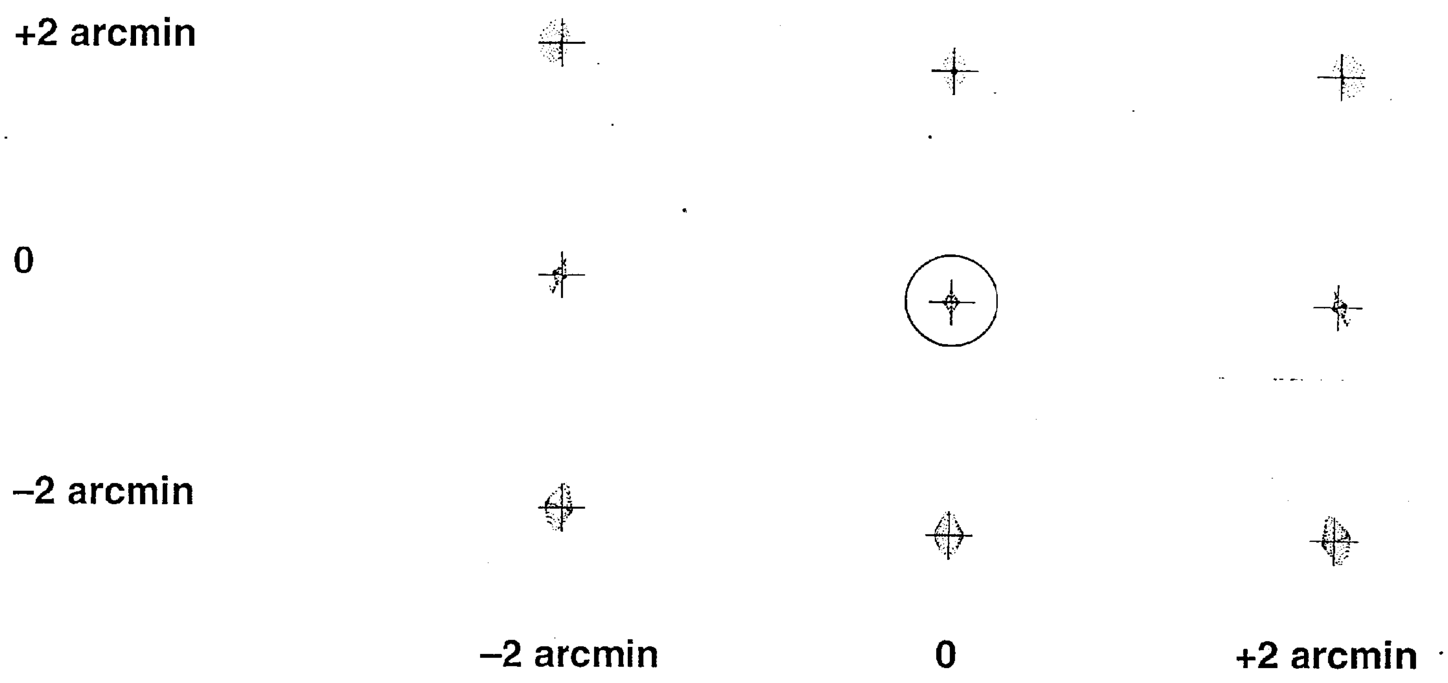
What are the constraints on the Cold-Box?

- Position in the instrument
- Clearance to optical components

K. Dohlen, Observatoire de Marseille

PHOT-BOL

Optical performance:



SPEC-BOL

Optical concept:

Flat grating spectro, spherical reflecting collimator, Quartz camera lens
- All-reflective design to be studied

Spectral chopping by wobbling the grating

Spectral range by turning the grating

Want beam Ø *large* for high R and small grating angle

Want beam Ø *small* for fast chopping (10 Hz)

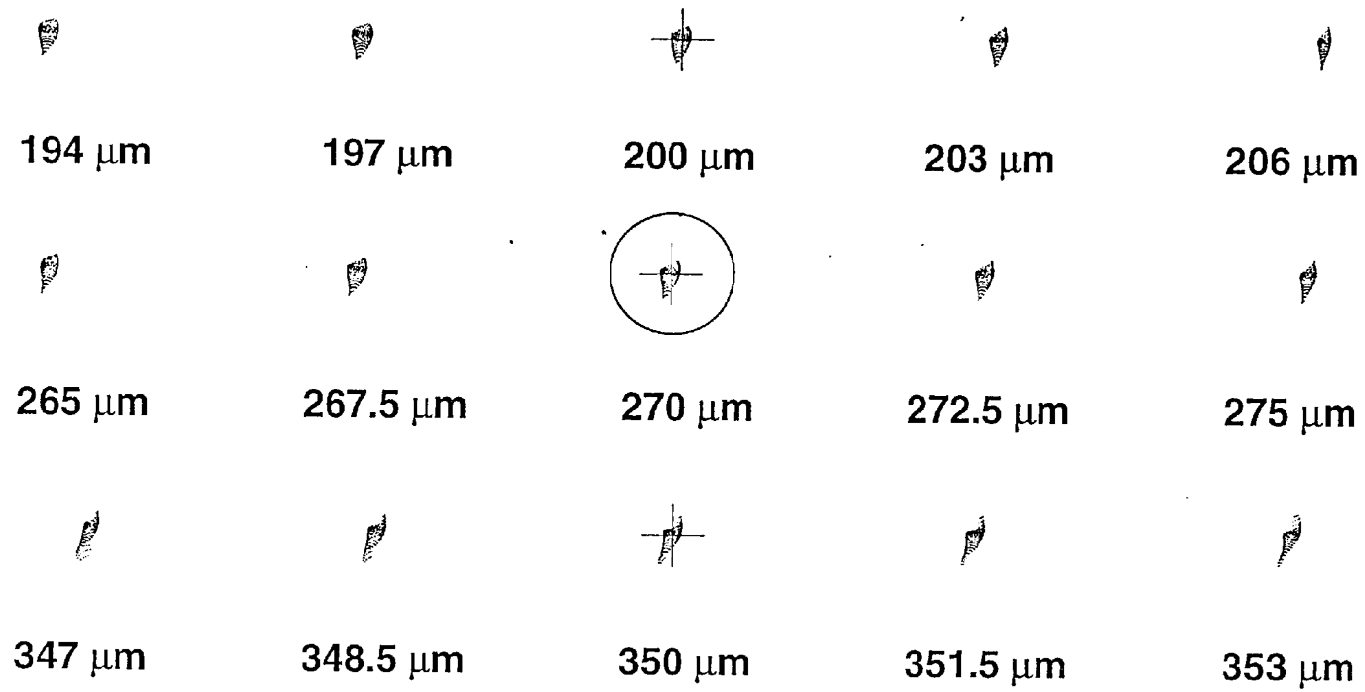
Consider realistic beam Ø 60 mm

Grating 5 g/mm gives:

Wavelength (µm)	Grating angle (deg)	Grating width (mm)	FWHM, λF (mm)	Theoretical R	Detector R
200	30	69	1	346	173
270	42	81	1.35	407	274
350	61	124	1.75	620	542

SPEC-BOL

Optical performance:



K. Dohlen, Observatoire de Marseille

SPEC-BOL

Sampling:

Obtain theoretical R by shifting the line by ½ pixel
By-product of spectral chopping

Grating efficiency: [Loewen et. al. Appl. Opt, **16**, 2711 (1977)]

Highly polarizing
> 50% according to infinite conductivity theory

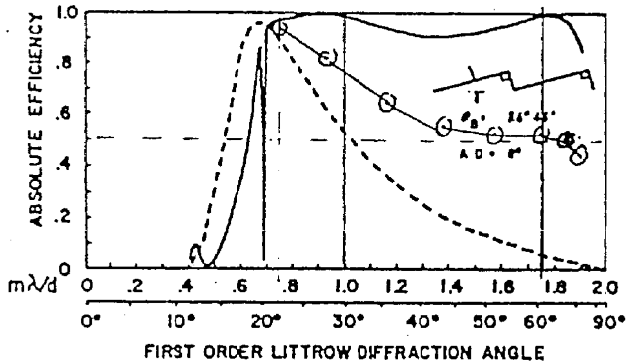


Fig. 5. Same as Fig. 1, except $\theta_B = 26.75°$.

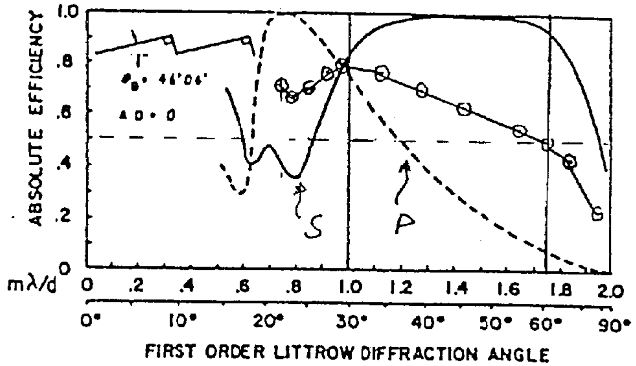


Fig. 6. Same as Fig. 1, except $\theta_B = 46°$.

(31)

SPEC-BOL

Technological aspects:

Grating

Similar to LWS in size, groove density and blaze angle

Flat, no Schmidt profile required

Drive mechanism

Bendix mechanism known from LWS

OK for > ±15° (LWS: ±7°)

OK for 10 Hz

Guaranteed for > 200 000 cycles

CONCLUSION

Lamarre's original design optically good but low transmittance, T ~ 46%

Dual channel system proposed:

PHOT-BOL:

- Identical to Lamarre's system but no filters nor F-P
- Single lens, T ~ 68%
- All-reflective to be studied

SPEC-BOL:

- Flat grating spectro
- Grating and drive comparable with LWS
- Single lens T ~ 68%, Grating eff. > 50%, Total T > 34%
- All-reflective to be studied

K. Dohlen, Observatoire de Marseille

Dispersion.

$$D = \frac{d\beta}{d\lambda} = \frac{1}{\lambda}(\sin\beta - \sin\alpha)\cos\beta.$$

Resolving Power

$$R = \frac{w(\sin\beta - \sin\alpha)}{\lambda}.$$

[450nm ↳ 1963 @ 250 μm]

i) Dispersion for $\alpha = 60$ $\beta = 13$

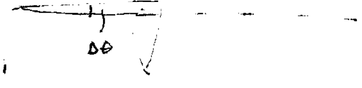
$$D = 4.25 \times 10^{-3} \ R/\mu m$$

Resolving power @ 250 nm 1304

$\Rightarrow \Delta\lambda = 0.19\,nm.$

FOR 1 RES ELEMENT $\Delta\beta = 5.11 \times 10^{-4}\,R.$

@ 1950 mm $= 0.933$ mm.



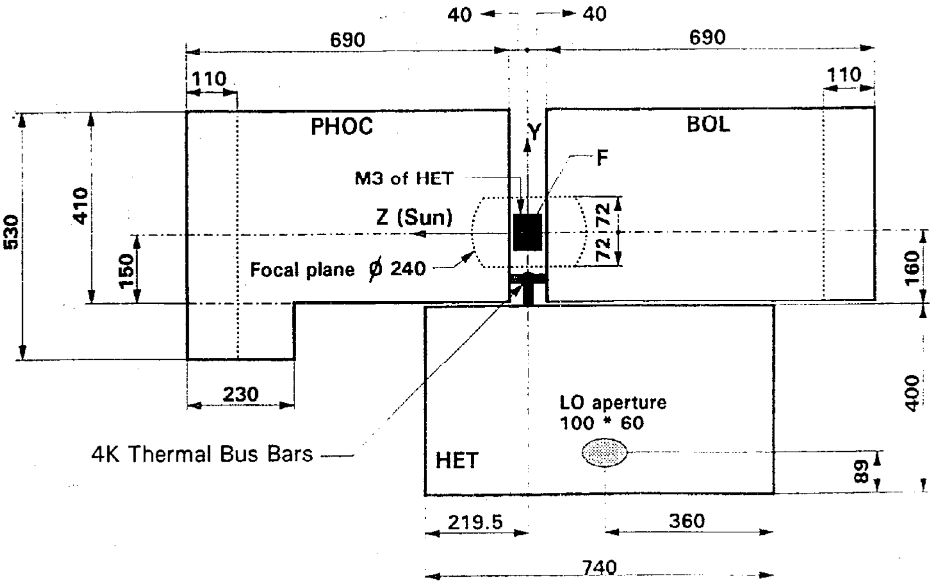


Figure 1: The *FIRST* focal plane, top view towards (−x)
The division of the focal plane between the three instruments as seen from above. The sun direction is perpendicular to the dividing lines. Units are in mm.

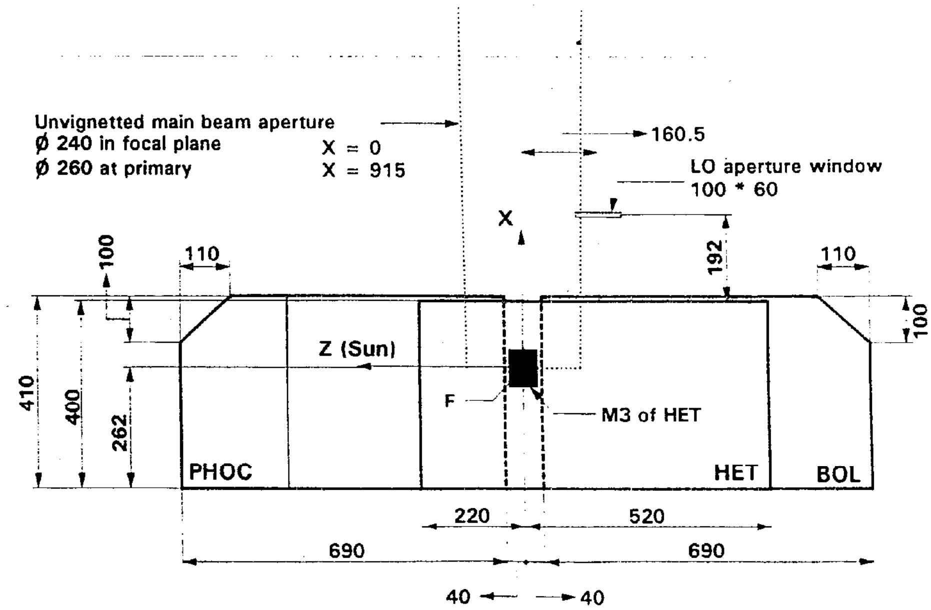


Figure 2: The *FIRST* focal plane, side view towards (+y)
The division of the focal plane between the three instruments as seen from one side. The instruments are mounted on a cooled mounting plate.

35

Baseline Assumptions

- Resolving Power:

  @250μm ~1000 <u>nom</u>

- Wavelength coverage

  200 - 350μm

- Grating Temperature

  <5K

- Photometry/Spectrometry

  Divided before 4°K enclosure

  Do not require same FOV as per PPD (228*)

- Imaging Spectroscopy

  Yes

- System Throughput

  > 10% Spect

  > 30% Phot

- Straylight control

  Pupil as close as possible to grating

  Minimise beam folding

  Lyot stop in photometer

- FOCAL PLANE

PHOTOMETER — 2 CHANNELS ~~WITH DICHROS~~

AS COMPACT AS POSSIBLE

PACKING DENSITY ~ ~~2~~ 4 mm Ø

25 SPECTROSCOPY

61 SW PHOTOMETRY

37 LW — " —

SPECTROMETER 5×5 ARRAY 4mm PIXELS

- CHOPPING

SKY CHOPPING FOR PHOTOMETER

" " FOR SPECTROMETER

- COLLIMATOR (FOR SLIT)

- FINAL OPTICS

F3

$$R = \frac{W(\sin\beta - \sin\alpha)}{\lambda}.$$